34 Vent Fauna in the Okinawa Trough

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Abstract

In deep-sea hydrothermal vent fields, faunal distribution is associated with geochemical environments generated by hydrothermal vent activity. The Okinawa Trough is located between the Eurasian Continent and the Ryukyu Arc, and is characterized by sediment-associated fauna associated with vents. In this chapter, the faunal distribution in hydrothermal vent fields in the Okinawa Trough is summarized at inter- and intra-field levels, and its relationship with geochemical environments and species-specific ecologies is discussed. Although the zonation of sediment-associated fauna is not distinct, the fauna on rocky seabed can be categorized into four zones based on thermal conditions. Genetic connectivity among conspecific populations in the Okinawa Trough appears to be common; further, a few faunal groups, such as tubeworms, show connectivity to regions outside of the Okinawa Trough. The faunal composition of vent communities in the Okinawa Trough has been categorized into three groups: the Minami-Ensei Knoll, Yoron Hole, and middle-southern Okinawa Trough. To determine more precisely the relationships between faunal composition and environmental factors in the Okinawa Trough vent fields, both generalized and vent-specific environmental factors should be measured simultaneously with quantitative faunal sampling for analyses.

Keywords

Biodiversity • Connectivity • Faunal similarity • Zonation

34.1 Background

Deep-sea hydrothermal vents are among the most flourishing deep-sea environments, due to the associated chemosynthetic bacterial productivity. The Okinawa Trough is a backarc basin located between the Eurasian continent and the Ryukyu island arc. The first hydrothermal vent field in the Okinawa Trough was discovered in the 1980s at the JADE site, Izena Hole (Halbach et al. 1989), and geological and geochemical knowledge has been accumulated since then. In total, eight hydrothermal vent fields, i.e. the Minami-Ensei Knoll, the Yoron Hole, the Iheya Ridge, the Iheya North Knoll, the Izena Hole, Irabu Knoll, the Hatoma Knoll and the Daiyon-Yonaguni Knoll, have been discovered to date in the Okinawa Trough, and exploration is still in progress (see Fukuba et al. Chaps. 38 and 39; Yanamaka

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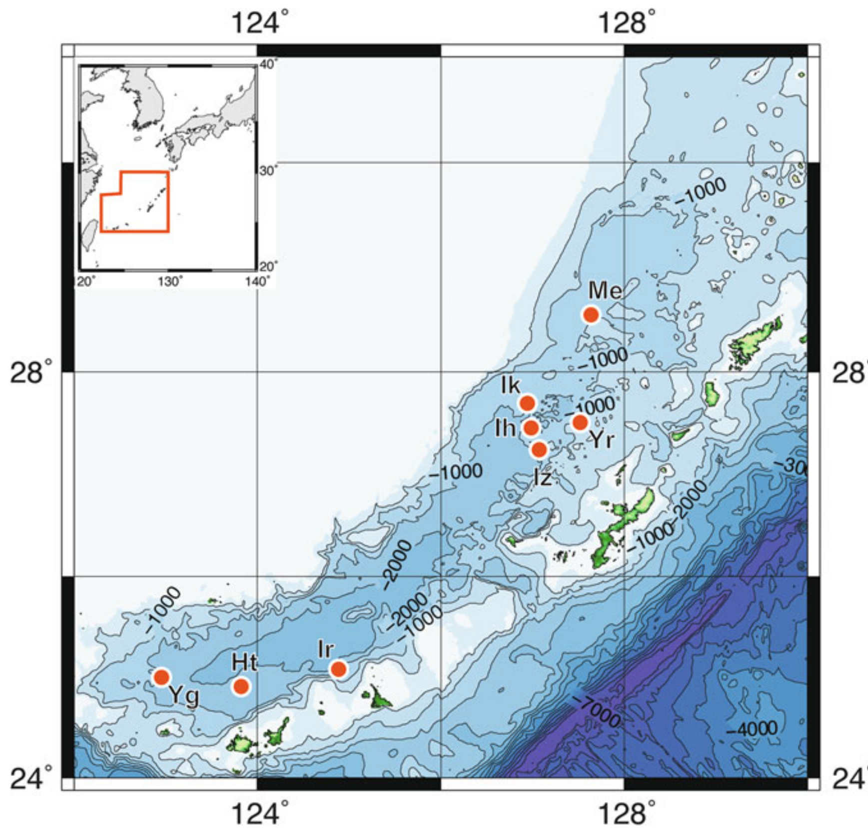


Fig. 34.1 Distribution of deep-sea hydrothermal vent fields in the Okinawa Trough. *Me* Minami-Ensei Knoll (D = 600–800 m), *Yr* Yoron Hole (D = 580 m), *Ik* Iheya North Knoll (D = 900–1,000 m), *Ih* Iheya Ridge (D = 1,300–1,500 m), *Iz* Izena Hole (D = 1,300–1,600 m), *Ir* Irabu Knoll (D = 1,650 m), *Ht* Hatoma Knoll (D = 1,400–1,530 m), *Yg* Daiyon-Yonaguni Knoll (D = 1,320–1,387 m)

et al. Chap. 40). Rifting of the Okinawa Trough appears to have started from the southern end. In terms of water columns, the Kuroshio Current flows from the southern end of the Okinawa Trough to the Kerama Gap or to the Japan Sea. The details of the vent fields in the Okinawa Trough are summarized by Ishibashi et al. (Chap. 29).

The faunal assemblages associated with hydrothermal vents in the Okinawa Trough were first summarized for the Iheya Ridge (Ohta 1991; Kim and Ohta 1991) and updated by Hashimoto et al. (1995) with extensive descriptions of the vent fauna in the Minami-Ensei Knoll and comparisons with vent fauna in the north (Minami-Ensei Knoll) and middle (Iheya Ridge) parts of the Okinawa Trough (Fig. 34.1). In the early 2000s, reports described vent fauna in the southern part of the Okinawa Trough (Tsuchida et al. 2000; Fujikura et al. 2001). On the basis of these descriptions, the fauna associated with hydrothermal vent fields in the Okinawa Trough appear to show similarities to those in methane seep sites in Sagami Bay due to the dense sedimentation (Fujikura et al. 1995; Watanabe et al. 2010).

In this paper, we summarize the previous research and recent results from the TAIGA project on vent fauna in the Okinawa Trough, to focus on (1) species distribution and population connectivity among the vent fields, (2) the zonation of fauna around vents, and (3) faunal similarities among vent fields in the Okinawa Trough.

34.2 Distribution and Connectivity of Vent Fauna in the Okinawa Trough

Vent fauna in the Okinawa Trough have been summarized previously (Kojima 2002; Fujikura et al. 2008; Watanabe et al. 2010); however, the community structure is not yet fully understood due to a lack of quantitative information. Recent comprehensive DNA barcoding analyses have revealed the existence of cryptic species, or morphologically similar species, particularly among the polychaetes and small gastropods. On the other hand, the possibility of synonymy is arising. Therefore, verification of the distributional records of vent fauna in the Okinawa Trough is still in progress. To date, a total of 109 species has been reported in and near vent fields in the Okinawa Trough (summarized in Table 34.1). In this section, previous reports are briefly summarized for the three major taxa (Annelida, Arthropoda, and Mollusca), together with recent distributional remarks and results of genetic analyses from the TAIGA project, which infer population connectivity.

Annelida. In total, 36 species have been reported in the Okinawa Trough hydrothermal vent fields, but as yet no species strictly endemic to the region have been recognized. Vestimenteiferan tubeworms are among the conspicuous

Table 34.1 Species list of vent fauna in the Okinawa Trough

		Minami-Ensei Knoll	Yoron Hole	Iheya North Knoll	Iheya Ridge	Izena Hole	Irabu Knoll	Hatoma Knoll	Daiyon-Yonaguni Knoll
Porifera	Rossellidae gen. et sp.				+				
	Pheronema ijimai	+			+	+			
	Pheronema sp.	+							
	Euplectella spp.	+			+				
	Poecilosclerida gen. et sp.	+							
Mollusca (Gastropoda)	*Leptochiton tenuidontus*				+				
	Thermochiton undocostatus				+				
	Bathyacmaea secunda	+		+	+	+	+	+	+
	Bathyacmaea tertia			+					
	Pyropelta ryukyuensis							+	+
	Lepetodrilus japonicus	+							
	Lepetodrilus nux	+		+	+	+	+	+	+
	Puncturella parvinobilis	+		+		+			
	Puncturella rimaizenaensis					+			
	Margarites ryukyuensis			+	+	+	+	+	+
	Margarites shinkai					+			
	Iheyaspira lequios			+	+	+			
	Iheyaspira sp.	+							
	Peltospiridae gen. et sp.								+
	Cantrainea jamsteci	+		+		+			
	Cantrainea nuda	+							
	Shinkailepas kaikatensis		+						
	Shinkailepas aff. myojinensis	+	+			+			
	Shinkailepas sp.			+					
	Provanna aff. glabra (MO1)		+	+	+	+	+	+	+
	Provanna sp., MO2					+	+	+	
	Provanna sp., MO3	+							
	Desbruyeresia sp.					+			
	Oenopota sp.			+					
	Eosipho desbruyeresi nipponensis			+					
	Neptunea insularis robusta	+							
Mollusca (Bivalvia)	*Eulimella* sp.			+					
	Solemya flava				+				
	Bathymodiolus aduloides	+			+				
	Bathymodiolus japonicus	+		+					
	Bathymodiolus platifrons			+	+	+		+	+
	Calyptogena okutanii			+	+				
	Calyptogena nankaiensis			+					
	Calyptogena kawamurai	+							

(continued)

Table 34.1 (continued)

		Minami-Ensei Knoll	Yoron Hole	Iheya North Knoll	Iheya Ridge	Izena Hole	Irabu Knoll	Hatoma Knoll	Daiyon-Yonaguni Knoll
Annelida	*Capitella* sp.	+							
	Nicomache ohtai					+			
	Maldanidae gen. et sp.	+							
	Paraonidae gen. et sp.	+							
	Brachipolynoe pettiboneae				+	+			+
	Brachipolynoe spp.			+		+		+	+
	Branchinotogluma (=*Opisthotrochopodus*) sp.			+		+			
	Shinkai longipedata			+	+				
	Shinkai semilonga			+					
	Mytilidiphila enseiensis	+							
	Mytilidiphila okinawaensis	+			+				
	Iheyomytilidicola tridentatus				+				
	Ophryotrocha sp.	+							
	Schistomeringos sp.	+							
	Eunice masudai	+							
	Eunice northioidea	+							
	Eunice spp.	+	+			+		+	
	Sabellidae gen. et sp.	+							
	Lamellibrachia sp. L1			+	+				
	Paraescrpia echinospica				+				
	Escarpia sp. E2				+				
	Alaysia sp. A2								+
	Alaysia sp. A4			+	+	+	+		
	Cirratulidae gen. et sp.			+					
	Paralvinella aff. hessleri		+	+	+	+		+	+
	Paralvinella aff. unidentata							+	+
	Amphisamytha aff. galapagogensis			+	+	+	+		
	Amphisamytha sp.					+		+	
	Glyphanostomum? sp.					+		+	
	Ampharetidae gen. et sp.	+			+	+		+	+
	Terebellidae gen. et sp.	+							
	Hesionidae gen. et sp.					+			
	Nephtyidae gen. et sp.		+			+			
	Cerviniidae gen. et sp.	+							
	Hyphalion sp.	+							
Arthropoda	*Ashinkailepas seepiophila*			+	+				
	Leucolepas longa			+	+				+
	Neoverruca sp.			+	+	+	+	+	+
	Alvinocais brevitelsonis	+							
	Alvinocais dissimilis	+							
	Alvinocais longirostris			+	+	+	+	+	+
	Alvinocais sp. type SM						+		
	Shinkaicaris leurokolos	+	+	+		+	+	+	+
	Glyphocrangon sp.							+	
	Paracrangon sp.	+							
	Lebbeus shinkaiae	+	+		+	+	+	+	+

(continued)

Table 34.1 (continued)

		Minami-Ensei Knoll	Yoron Hole	Iheya North Knoll	Iheya Ridge	Izena Hole	Irabu Knoll	Hatoma Knoll	Daiyon-Yonaguni Knoll
	Stylodactylus major							+	
	Munidopsis ryukyuensis					+	+	+	
	Munidopsis naginata							+	
	Shinkaia crosnieri	+		+	+	+	+	+	+
	Munida sp.				+				
	Paralomis jamsteci	+							
	Paralomis verrilli				+			+	
	Paralomis multispina	+							
	Gandulfus yunohana	+							
	Geryon aff. granulatus	+							
	Xanthidae sp.		+						
	Gnathiidae sp.		+						
Echinodermata	*Ceranaster misadiensis*	+							
	Synallactidae gen. et sp.				+	+			
Chordata	*Eptatretus okinoseanus*	+			+				
	Myxine garmani	+							
	Synaphobranchus affinis				+				
	Ilyophis brunneus				+				
	Aldvovandia affinis				+				
	Zoarcidae gen. spp.	+		+	+	+			+
	Psychrolutes inermis	+							
	Symphurus cf. *orientalis*	+							
	Liparidae sp.					+			

Updated from Fujikura et al. 2008

fauna in the vent fields. Three species have been separately reported in the Okinawa Trough vent fields, but these are also found in the methane seep faunas: *Lamellibrachia* sp. in the Iheya Ridge and the Iheya North Knoll; *Paraescarpia echinospica* in the Iheya Ridge; and two lineages of *Alaysia*, A2 in the Daiyon-Yonaguni Knoll and A4 in the Iheya Ridge, the Iheya North Knoll and the Izena Hole (Fujikura et al. 2008). Two unidentified species of tubeworm were reported in Depression B of the Minami-Ensei Knoll (Hashimoto et al. 1995; Fig. 34.2a). The tubeworm clump possibly consisted of *Alaysia* and *Lamellibrachia*; however, identification to the species level has been impossible. Population genetic analyses of tubeworms showed no differences among the populations in the Okinawa Trough, or from those of populations outside of the Okinawa Trough (Watanabe et al. 2010).

Other than tubeworms, the connectivity among populations of annelids has yet to be examined. For the polychaetes, classification of the collected animals is not sufficient for a comparison of the faunal composition among the vent fields. Ampharetid polychaetes are, however, abundant in the middle and southern parts of the Okinawa Trough, and are frequently associated with a squat lobster, *Shinkaia crosnieri* (Fig. 34.2). Recent DNA barcoding indicates the existence of at least three different clusters ampharetid polychaetes in the Okinawa Trough (data not shown), probably including the "ampharetid sp." reported by Hashimoto et al. (1995). Two *Eunice* species have been described (*E. masudai* and *E. northioidea*), and the existence of further species in this genus has been indicated (Hashimoto et al. 1995). As most of the species-level composition of polychaete fauna in the Okinawa Trough is still incomplete, we have only identified them to the genus level. However, it is apparent that the diversity of vent polychaetes in the Okinawa Trough is underestimated, and a detailed re-examination is accordingly required.

Arthropoda. In total, 23 species have been reported in the Okinawa Trough hydrothermal vent fields, and three dominant species, *Shinkaia crosnieri*; a shrimp with a pair of unfused dorsal eyes, *Shinkaicaris leurokolos*; and a shrimp with stalked eyes, *Lebbeus shinkaiae*, are treated as endemic to this region. No bythograeid crabs have been reported.

Shinkaia crosnieri has been observed in most vent fields and is among the representative animals of the Okinawa Trough, although its abundance decreases in shallower vent fields such as the Minami-Ensei Knoll and it is absent from the Yoron Hole. *S. crosnieri* harbors bacterial symbionts in its ventral side (Watsuji et al. 2010) and the ecological characteristics are similar to those of *Kiwa* (Roterman et al. 2013). Genetic diversity is relatively high (Kumagai et al., Chap. 5), probably due to its high abundance caused by frequent reproduction to sustain a huge biomass.

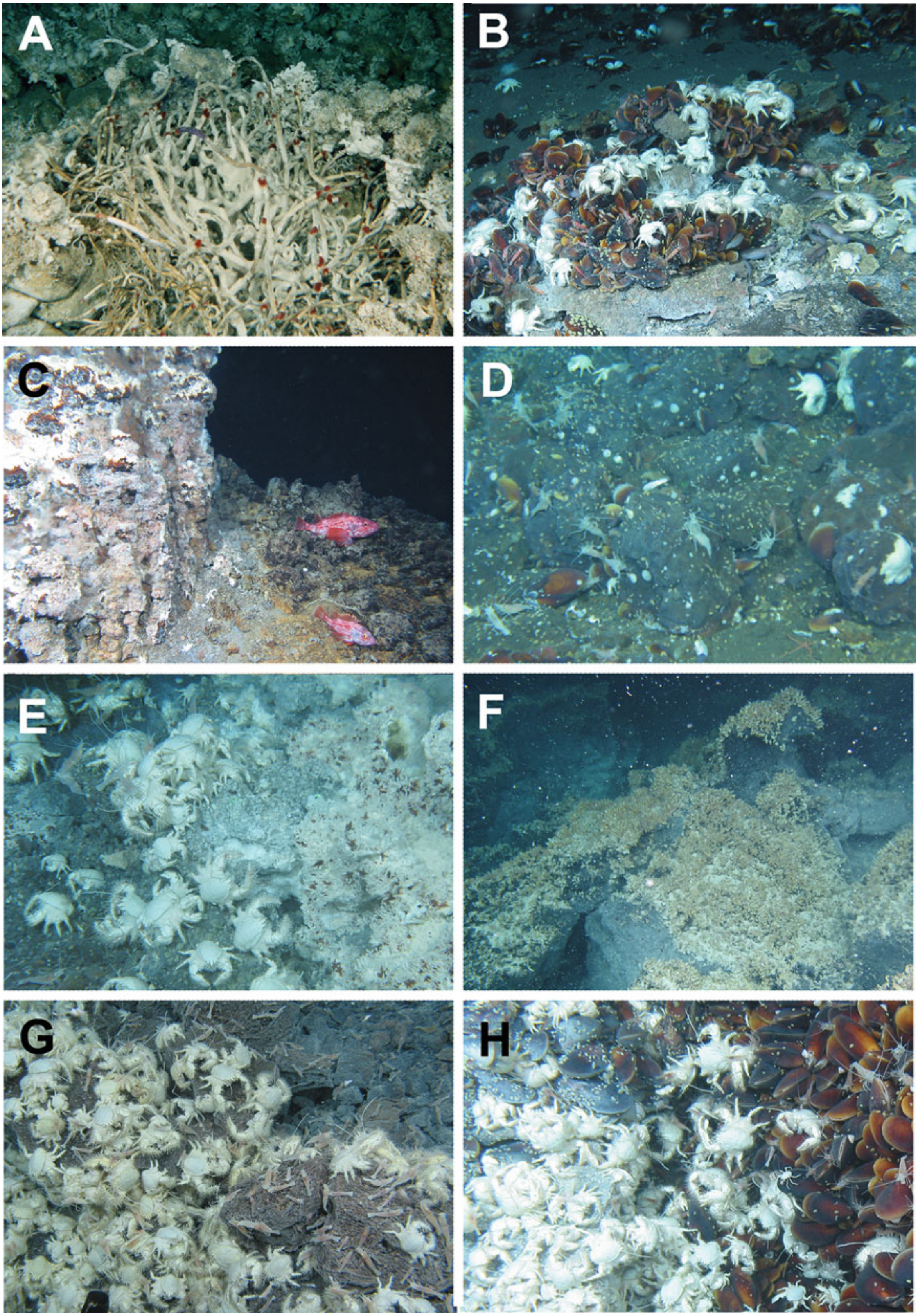


Fig. 34.2 Typical vent fauna in the Okinawa Trough. (**A**) tubeworm clump in the Minami-Ensei Knoll, (**B**) typical rocky fauna in the Minami-Ensei Knoll, (**C**) vent associated fauna in the Yoron Hole, (**D**) peripheral vent fauna in the Izena Hole, (**E**) high-temperature vent fauna in the Izena Hole, (**F**) barnacle-dominated zone in the Irabu Knoll, (**G**) typical rocky fauna in the Irabu Knoll, (**H**) typical rocky fauna in the Hatoma Knoll

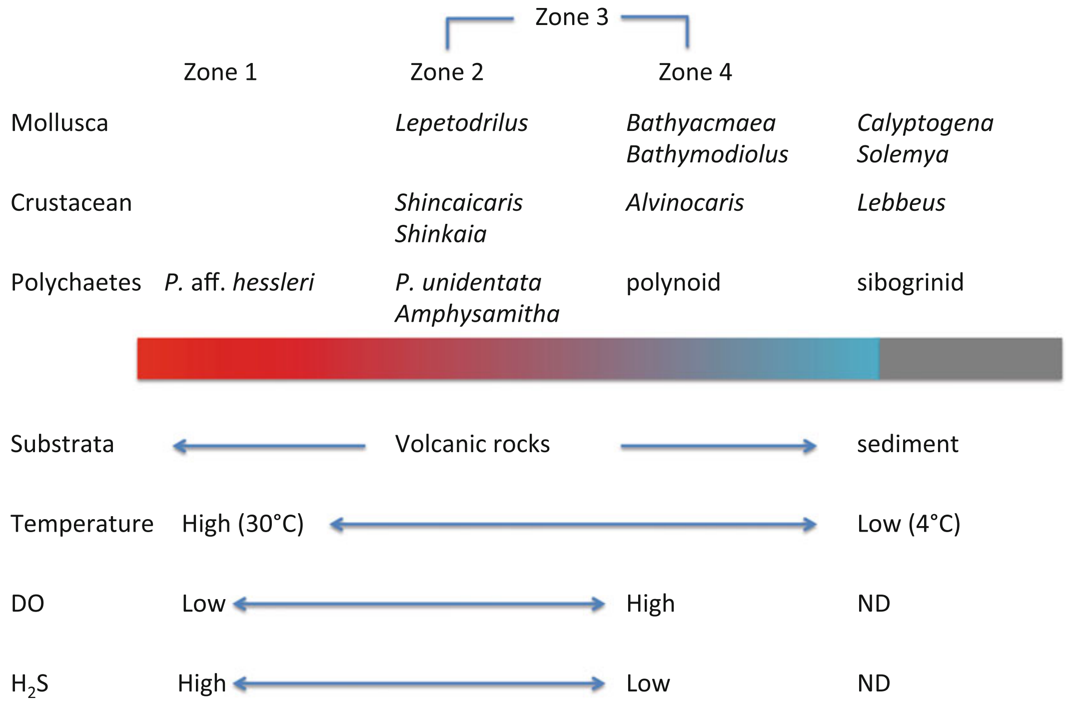


Fig. 34.3 Summary of zonation of vent fauna in the Okinawa Trough. *ND* not determined

Alvinocaridid shrimps are the second most dominant crustaceans in the Okinawa Trough vent fields; however, the two reported genera, *Alvinocaris* and *Shinkaicaris*, have different distributions (Komai and Segonzac 2005). The *Alvinocaris* shrimps have been reported in a wide area in the Okinawa Trough: *A. dissimilis* in the Minami-Ensei Knoll, and *A. longirostris* in all the other vent fields except for the Yoron Hole (Fujikura et al. 2008). On the other hand, *Shinkaicaris leurokolos*, whose distribution was thought to be restricted to the Minami-Ensei Knoll, now appears to be distributed in all the known vent fields in the Okinawa Trough (Yahagi per. com).

Lebbeus shinkaiae, which is a recently described shrimp, but which has also been reported as *Lebbeus washingtonius* or *Lebbeus* sp. (Komai et al. 2012), is also widely distributed, but is only reported from the Okinawa Trough. This shrimp is not aggregated and is commonly distributed near peripheral areas of vent fields.

A barnacle of the genus *Neoverruca* is patchily but abundantly distributed in all the Okinawa Trough vent fields except for the Minami-Ensei Knoll and Yoron Hole. Among the local populations in the Okinawa Trough, no genetic differences have been detected and their population expansion date has been estimated to be earlier than that in the Izu-Ogasawara Arc vent fields (Watanabe et al. 2005). Rearing experiments on larvae of this barnacle revealed that high temperature surface water may act as a dispersal barrier for this species (Watanabe et al. 2006).

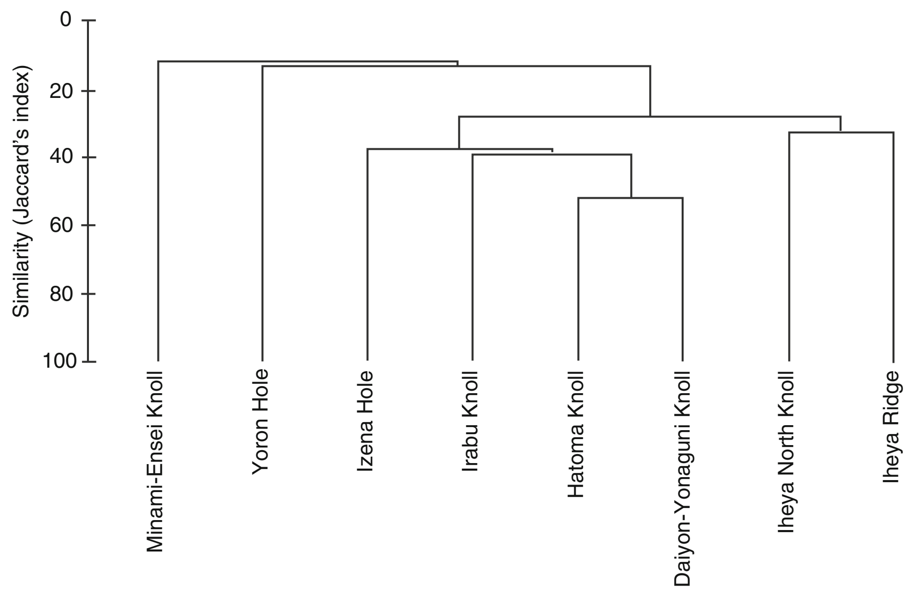
Mollusca. In total, 34 species have been reported in the Okinawa Trough hydrothermal vent fields, and most vent gastropod species are thought to be endemic to this region.

Large clams of the genus *Calyptogena* s.l. are distributed only in sedimentary fields (Kim and Ohta 1991) in the hydrothermal vent fields of Minami-Ensei Knoll and Iheya Ridge and Iheya North Knoll in the Okinawa Trough. Hitherto, three species have been reported, and the population genetic structure has been examined for *C. kawamurai* and *C. okutanii* (Watanabe et al. 2010, based on the data in Kojima et al. 2001, 2006). In both cases, populations in the Okinawa Trough were significantly different from those outside of the Okinawa Trough. No differences were detected between *C. okutanii* populations in vent fields of the Iheya Ridge and Iheya North Knoll.

Bathymodiolus mussels are among the representative animals of the Okinawa Trough, and three species are distributed in the different ranges: *B. japonicus* in Minami-Ensei Knoll (Fig. 34.2b), *B. aduloides* in the Minami-Ensei Knoll and Iheya Ridge, and *B. platifrons* in all the vent fields except for the Minami-Ensei Knoll and Yoron Hole (Fig. 34.2, Table 34.1). The population connectivity of *B. platifrons* was examined using partial sequences of mitochondrial NADH dehydrogenase 4 (ND4), and the most dominant haplotype was shared between populations inside and outside of the Okinawa Trough (Kyuno et al. 2009), inferring connectivity between the populations.

Provanna snails are the most abundant macrofauna in the Okinawa Trough vent fields. They are associated with both

Fig. 34.4 Results of clustering analysis of faunal similarity among the eight vent fields listed in Table 34.1



hard and soft substrata, both in vents and seeps (Fujikura et al. 2008). The *Provanna* gastropods in vent fields in the Okinawa Trough were first referred to as *P. glabra* based on the populations in Sagami Bay, but certain morphological differences were identified; therefore, they have been referred to as *P.* aff. *glabra* for more than 10 years (Fujikura et al. 2008). Morphometric and DNA barcoding analyses is now in progress and it shows the possibility that more than 2 lineages of *Provanna* gastropods are distributed in the Okinawa Trough.

A small limpet, *Lepetodrilus nux*, is a species endemic to the Okinawa Trough and has been found in all of the vent fields except for the Yoron Hole. It is sometimes associated with *S. crosnieri* and *B. platifrons*, but can also be found on inorganic hard substrata. *Lepetodrilus japonicus* was described from a vent field in the Minami-Ensei Knoll, but a recent investigation could not determine its distribution in Depression C of the knoll. On the other hand, *L. nux* appears to be distributed in the Minami-Ensei Knoll in addition to the previously known vent fields (Nakamura et al. 2014).

A small snail, *Iheyaspira lequios*, is a species only found in hydrothermal vent fields in the Okinawa Trough. Recently, a second species of the genus *Iheyaspira*, *I. bathycodon*, was reported from the Mid-Cayman Rise in the Caribbean Sea (Nye et al. 2013). This patchy worldwide distribution of a vent-endemic genus is quite rare, as there are many vent fields located between the Okinawa Trough and the Caribbean Sea. *Iheyaspira* gastropods are usually smaller than 5 mm in shell width, in the Okinawa Trough, and may be missed or misidentified due to their small size. A detailed examination of both morphology and genetics is required to understand the distributional pattern of *Iheyaspira* gastropods, not only in the Okinawa Trough but also on a global scale.

Other Phyla. Poriferans, anthozoans, echinoderms, and fishes are common marine fauna but not well described for the areas near vent fields in the Okinawa Trough. Poriferans are abundant in the Minami-Ensei Knoll (Fig. 34.2a), but to date no species have been identified. Some echinoderms such as *Ceramaster* asteroids and unidentified ophiuroids have been reported in Depression B in the Minami-Ensei Knoll and the CLAM site in the Iheya Ridge (Hashimoto et al. 1995; Kim and Ohta 1991). Recently, the reproduction of a liparid fish, *Careproctus rhodomelas*, in the Hatoma Knoll was reported (Takemura et al. 2010); however, for the other fishes, almost nothing has been reported due to the difficulty of sampling. These fauna may be important as predators in such ecosystems, and detailed observations are required for elucidating trophic interactions.

34.3 Faunal Zonation in a Vent Field

Vent fauna show variation along steep environmental gradients, or patchiness, which is referred to "zonation." In the Okinawa Trough, hydrothermal vents host two types of fauna: rocky seabed fauna associated with direct vent activity (rock-associated fauna), and epi- and infauna indirectly supported by vents (sediment-associated fauna). Generally, faunal composition differs among substrata (Tunnicliffe et al. 2003). These differences in the vent fields in the Okinawa Trough were first mentioned by Kim and Ohta (1991) based on the observation of vent fauna in the CLAM (sedimentary) and PYRAMID (rocky) sites of the Iheya Ridge. Subsequently, two neighboring vent sites with differing fauna were reported in Depression B (sedimentary) and C (rocky) in the Minami-Ensei Knoll (Hashimoto et al. 1995). This section summarizes zonations in the rocky and sedimentary habitats in the vent fields in the Okinawa Trough.

Rock-Associated Fauna. Rocky fauna are generally dominant in deep-sea hydrothermal vent fields. The zonation sequence of epifauna on the rocky substrata has been categorized into 4 zones in the Iheya North Knoll: Zone 1 (<0.2 m from vent), no fauna except for occasional invasion by shrimps; Zone 2 (0.2–0.8 m from vent), *Shinkaia crosnieri* aggregation with shrimps; Zone 3 (0.8–2.5 m from vent), co-occurrence of *S. crosnieri* and *Bathymodiolus platifrons* with two limpets (*Bathyacmaea secunda* and *Lepetodrilus nux*) and shrimps; and Zone 4 (>2.5 m from vent), *B. platifrons* without *S. crosnieri* (Tokeshi 2011). Additional observations have updated the faunal composition of each zone (Figs. 34.2 and 34.3). Zone 1, nearest to hydrothermal venting, is inhabited by a dense assemblage of *Paralvinella* aff. *hessleri* with white tubes (Fig. 34.2e), although congeneric *P.* aff. *unidentata* without tubes are scattered near vents. The surrounding area (Zone 2) is inhabited by *Shinkaicaris leurokolos* and *S. crosnieri*. *S. crosnieri* is sometimes associated with *L. nux* and ampharetid polychaetes and red copepods. Outside of the *S. leurokolos*–*S. crosnieri* assemblage (Zone 4), *B. platifrons*-hosted fauna are distributed. *Alvinocaris longirostris*, a shrimp without a dorsal eye, and the limpets *B. secunda* and *L. nux* are associated with this fauna. The transitional zone from Zone 2 to Zone 4 is Zone 3, which shares fauna with both zones.

For the zonation associated with hydrothermal vents, temperature must be an important factor. There is some evidence to show that temperature contributes to controlling faunal zonation. For instance, in the Okinawa Trough, the difference in temperature effects was also observed for two vent barnacles; *Ashinkailepas seepiophila* was found on a dead chimney and *Neoverruca* sp. on an active chimney, as the effects of rearing temperature on larval duration of these two species were different (Yorisue et al. 2013). Other environmental factors, such as salinity, dissolved oxygen (DO), and the concentration of H_2S, may contribute to the zonation, but there is no supportive evidence for this from the northwestern Pacific. In vent fields in the southwestern Pacific, sulfide concentration and DO, in addition to temperature, appear to contribute to the gradient distribution of vent fauna (Podowski et al. 2010).

Sediment-Associated Fauna. Sedimentary fauna associated with vents is found in the northern and middle part of the Okinawa Trough. This fauna differentiate the vent fauna in the Okinawa Trough from that of other vent fields in the northwestern Pacific and contribute to the species diversity of the Okinawa Trough. The zonation sequence of sediment-associated fauna is still unclear as it is difficult to stratify sediment with infauna to determine the relationships between environmental gradients and faunal distribution in a vertical spectrum. On the other hand, horizontal zonation has been observed in some methane seep sites. The relationships between the concentration of methane and faunal distribution have been discussed both from the perspective of a toxin for animals and as a substrate for chemosynthetic production (e.g. Barry et al. 1997). However, in general, faunal distribution in marine environments is explained by more generalized factors, such as temperature, salinity, and the concentration of DO. Indeed, the distribution of *Calyptogena* s.l. assemblages associated with hydrothermal vents and methane seeps in the Okinawa Trough and Sagami Bay could be explained by temperature and salinity (Watanabe et al. 2013). Although the vertical distribution of infauna is still unclear, the importance of infauna as a disturber of sediment has been noted in deep-sea reducing environments (Seike et al. 2012).

Vesicomyid or *Calyptogena* s.l. clams and solemiyd clams, along with tubeworms, are dominant in the sedimentary fauna in the Okinawa Trough vent fields. Recently, *Solemya flava* was described from a sedimentary vent field in the Iheya Ridge (Sato et al. 2013). The main difference from rocky fauna is that most sedimentary fauna are shared between methane seep sites in Sagami Bay and Nankai Trough (Watanabe et al. 2010). This can be attributed to the similarity of vent fauna in the Okinawa Trough to the methane seep fauna, in addition to the high concentration of methane and CO_2 in vent fluids (Sakai et al. 1990).

34.4 Faunal Resemblance in the Okinawa Trough

To show the overall similarity among the vent fauna in the Okinawa Trough, Jaccard's similarity index was calculated based on the species occurrence data (Table 34.1), and the results were presented using group-average clustering analysis (Fig. 34.4). Faunal similarity was lower than 60 % between all the vent fields, but the vent fauna was divisible into three groups at the 20 % similarity index: the Minami-Ensei Knoll, the Yoron Hole, and the others locations in the middle to the southern Okinawa Trough. Recent research has suggested that, although some fauna appear to be shared between the vent faunas in the Minami-Ensei Knoll and the other vent fields in the Okinawa Trough (e.g., *Shinkaicaris leurokolos* and *Lepetodrilus nux*), the fauna in the Minami-Ensei Knoll still retains high endemicity. However, the information on the sediment-associated fauna in the Minami-Ensei Knoll (Depression B) was not sufficient to examine the faunal resemblance. In the middle to southern Okinawa Trough, the faunal composition was relatively similar to the neighboring vent fields. The cluster of the

Iheya Ridge and Iheya North Knoll vent fauna is distinguished from those in the Izena Hole and Irabu, Hatoma and Daiyon Yonaguni Knolls because it included sediment-associated fauna.

There are several factors that contribute to inter-field faunal resemblance. In general, the diversity of deep-sea fauna varies according to depth (Rex and Etter 2010). Similar observation was made for deep-sea bivalves in chemosynthetic environments because the species show restricted ranges of vertical distribution (Fujikura et al. 2008). Indeed, the clusters of vent fauna in the Okinawa Trough are correlated with the depth range of each vent field (Fig. 34.4). The depth variation may act as both a dispersal barrier (pre-settlement) and physiological barrier (post-settlement). General oceanographic factors such as ambient temperature, salinity, and DO, are more important than the concentration of reduced chemicals in endmember fluid to field-level similarity, as the latter are quickly diluted by ambient seawater and seem to contribute to the species microdistribution in a vent field. To determine more precisely the relationships between faunal composition and environmental factors in the vent fields, both generalized and vent-specific environmental factors should be measured simultaneously for the analyses.

34.5 Conclusions

In this chapter, we summarized and updated the information on vent fauna in the Okinawa Trough. A total of 109 species are listed here; however, that number may be either an over- or under-estimate. Detailed morphological and genetic examination of vent fauna, particularly for polychaetes and small gastropods such as *Iheyaspira*, are required to confirm the existence of synonymous or cryptic species. The composition of sediment-associated fauna is genetically similar to that in methane seep sites outside of the Okinawa Trough, but its zonation is still unclear, as it's elucidation requires 3-dimensional observation of the sediment. On the other hand, the zonation of rock-associated fauna has been clearly determined, and most endemic species of the Okinawa Trough are found among the rock-associated fauna. The total diversity of vent fauna in the Okinawa Trough is attributable to the associated sediment-associated fauna and the wide depth range causing variation in both ambient temperature and that near hydrothermal vents. Although more than 20 years have passed since the discovery of vent fauna in the Okinawa Trough, further investigation is still required to understand their local biogeography.

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